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Blood Flow Restriction Training: A Tool to Enhance Rehabilitation and Build Athlete Resiliency

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Abstract

Blood flow restriction training (BFRT) is a tool utilized in rehabilitation and injury prevention to improve muscle strength and size, particularly in load-compromised individuals. BFRT facilitates gains in muscular strength and hypertrophy at lower loads, allowing for accelerated recovery and less disuse atrophy. BFRT must be applied appropriately and with caution, particularly in individuals with cardiovascular concerns. There are applications for BFRT across a wide spectrum of human performance training and in rehabilitation of both lower and upper extremity conditions, providing a high-quality adjunct to improve muscle strength, power, and endurance.

Level of Evidence

Level V, expert opinion.

Rehabilitation and injury prevention programs are constantly seeking ways to create an environment of progressive overload to produce more resilient, physically prepared individuals. This is particularly true in the athletic population. Athletes are frequently confronted with complicating factors both internal and external that make traditional progressive loading methods problematic or counterproductive. These include underlying concomitant conditions, chronic orthopaedic issues, acute tissue healing timelines, or even previous acute workloads that can create situations where they lack the structural and functional tolerance for an intensification in loading during training and rehabilitation.

Instead of constantly seeking progressive overload with an athlete during every session, the goal should be creating a progressive training stimulus within each interaction. Because the time in any athletic career is finite, the most needs to be made of each training session the athlete has available to them. The objective of rehabilitation and injury prevention is to gradually improve the structural and functional capabilities of the individual, allowing them the capacity to handle the demands of their tasks in their emergent environment. Blood flow restriction training (BFRT) provides the practitioner with the means to produce progressive stimulus to foster improvements in the structural and functional capabilities of load-compromised individuals. The purpose of this article is to explore the basic sciences, safety/contraindications, application, and utility of BFRT in rehabilitation and injury prevention.

Conventional Pathways to Strength and Hypertrophy

Progressive overload is a resistance training principle that hinges on gradually increasing the load the athlete is training under to drive the intended training stimulus.[1] One of the stimuli most frequently driven through resistance training is increasing muscle hypertrophy. Muscle hypertrophy is viewed as a foundational performance factor as the force a muscle can create is proportional to the physiological cross-sectional area (PCSA) of that muscle.[2,3] Resistance training has been shown to have a positive effect on increasing PCSA of muscles.[4,5] A progressive training stimulus capable of producing muscle hypertrophy can still be achieved by manipulating program variables other than load.[6] Increasing PCSA through muscle hypertrophy is a foundational performance precursor to the expression of maximal strength and power. Expression of maximal strength and power is heavily influenced by both inter- and intramuscular coordination as well as the specificity of the training in which the athlete participates.[7,8] There may be no greater modifiable variable in injury prevention and rehabilitation than improving the overall strength and hypertrophy of an athlete, and BFRT provides practitioners with a valuable tool to improve muscular strength and foster hypertrophy.[9]

The primary pathways to achieve muscle hypertrophy are metabolic stress, muscle damage, and mechanical tension.[6,10,11] Metabolic stress is the by-product of metabolites produced through anerobic glycolysis when engaging in glycolytic training. These metabolites include lactate, hydrogen ions, inorganic phosphate, and creatine. This metabolite accumulation is thought to be a mediator of the hypertrophic response specific to resistance training.[10] Exercise stress creates a hypoxic environment that decreases pH while increasing concentrations of hydrogen ions, CO_2, lactate, calcium, and reactive oxygen species. This combination results in increasing the release of myokines and cellular mechanotransduction to accommodate to cell swelling during loaded exercise, thereby furthering an increase in systemic anabolic signaling.[10,12,13] Muscle damage in the form of the deformation of the myofibrils through training produces an acute inflammatory response where, once the damage is perceived by the body, there is a hormonal response of various growth factors, leading to satellite cell proliferation, tissue repair, and muscle growth.[10,14,15] Mechanical tension is produced by force generation and stretching the muscle in a lengthened position, which increases as the load increases, resulting in a rise of type II muscle fiber recruitment to execute the task.[10,11]

This pursuit of type II muscle fiber activation is a primary rationale for the production of mechanical tension in resistance training. Conventionally, the pathway to improving hypertrophy is by using loads >60% of the 1-repetition max (1RM) with 8 to 12 repetitions per set, or strength 80% to 100% of 1RM with 1 to 5 repetitions per set.[16] However, muscle hypertrophy and activation of type II muscle fibers have been shown to be equally achieved across a variety of loading parameters, such as 30% to 80% of 1RM with a consistent theme of training to volitional fatigue.[11,16, 17, 18] Athletes who are load compromised secondary to structural or functional constraints may not tolerate heavy loads well and may need to use an alternative mode of exercise to elicit metabolic stress, muscle damage, and mechanical tension to stimulate the appropriate skeletal muscle response to resistance exercise and induce anabolism. BFRT is a modality that is capable of achieving these results in load-compromised individuals.

Basic Sciences

BFRT is a method of training that has utility in both rehabilitation and performance. It has been shown to elicit gains in strength and hypertrophy at significantly lower loads (<30% of estimated 1RM).[12,19] BFRT presents the practitioner with a method to elicit improvements in strength and hypertrophy in load-compromised individuals to accelerate recovery and mitigate disuse atrophy.[20] BFRT has also been shown to have benefits for cardiovascular fitness, pain attenuation, and improvements in bone density (Table 1).[21] The use of restricting proximal blood flow during exercise, or Kaatsu training, was first introduced in the 1960s by Dr. Yoshiaki Sato.[22]

Table 1.

Benefits of BFRT

Rehabilitation	Performance Training	Recovery
• Elicit muscle hypertrophy in load-compromised individuals.[33] • Preserve lower extremity bone mass and mitigate atrophy.[43, 44, 45, 46] • Summate type II muscle fibers both proximal and distal to the cuff.[24] • Induce both local and systemic anabolic signaling.[25]	• LL BFRT has been shown to be as effective at improving strength and hypertrophy in healthy individuals.[54,60] • To drive supplemental hypertrophy for targeted muscle groups to enhance performance in conventional tests of athletic performance.[19,63,66, 67, 68, 69, 70, 71, 72, 73, 74, 75, 76] • Utility improving aerobic fitness and anaerobic capacity.[81]	• Attenuate markers of exercise-induced muscle damage.[84] • Potential to reduce overall muscle soreness and enhance postexercise performance to better expedite athlete availability. [87,88]

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BFRT, blood flow restriction training; LL, low load.

The application of BFRT involves using either a pneumatic tourniquet system or a tourniquet cuff that is placed as proximal to the working limb as possible to mitigate compression of neurovascular structures around bony prominences.[23] Vascular structures under the tourniquet/cuff system are occluded with the intent to restrict venous return of blood flow and partially restrict arterial inflow within a working muscle. The decrease in venous outflow has been shown to lead to blood pooling and metabolite accumulation, while the decrease in arterial inflow leads to a decrease in oxygen to the working tissue, further exacerbating fatigue through the creation of a hypoxic environment.[20]

The use of BFRT enables the athlete to train at lighter loads while still achieving metabolic stress. This process is further enhanced by a combination of occlusion, muscle damage from the task of exercising, and mechanical tension secondary to training to volitional fatigue in a hypoxic environment.[12] This leads to an increase in metabolic stress through metabolite accumulation and is thought to facilitate signaling of hypertrophic pathways and increase motor unit recruitment of type II muscle fibers due to an earlier onset of fatigue.[21] It is important to note that there is a summation of type II muscle fibers both proximal and distal to the cuff when BFRT is utilized.[12,21] The rationale for the increase in muscle activation proximal to the placement of the cuff is recruitment of more proximal synergistic muscles later in the set when the distally occluded muscles are approaching volitional fatigue.[24] Additionally, gains in the contralateral extremity have also been shown after completing BFRT, suggesting systemic effects when appropriately utilized.[25]

BFRT training and low-intensity exercise are hypothesized to induce anabolism through metabolite accumulation via metabolic stress, leading to cell swelling.[21] This cell swelling distal to the cuff is thought to further propagate intracellular hypoxia, leading to anabolic and inflammatory signaling mechanisms.[17,19] Additionally, there is an increase in systemic anabolic signaling from the distal metabolite accumulation and proximally via downstream fatigue of the proximal musculature to accommodate for the workload.[12] The confluence of both the proximal and distal response to occlusion while exercising leads to a local and systemic anabolic signaling of an increase in growth hormone, insulin-like growth factor 1, vascular endothelial growth factor, myogenic stem cells, and muscle protein synthesis via mammalian target of rapamycin complex 1–mediated anabolism.[12,17,26,27] Insulin-like growth factor 1 plays a vital role in muscle hypertrophy by facilitating muscle protein synthesis through satellite cell proliferation and suppressing myostatin, which is a known negative regulator of muscle and bone anabolism.[12,14,15,28] Suppressed anabolic signaling has been shown to be present in individuals who may be inactive secondary to being load compromised or immobilized, which can contribute to a further decline in muscle mass.[29,30] PCSA is proportional to the force-generating capacity of the muscle, and disuse can lead to atrophy, which can reduce the PCSA of a muscle.[2,3] Muscle hypertrophy is a foundational performance factor in the expression of strength and power. In rehabilitation and sports performance, atrophy must be mitigated and hypertrophy prioritized to successfully improve athletic strength, power, and endurance. The mechanisms produced using BFRT can be extremely useful in facilitating this process.

Safety and Contraindications

Prior to utilizing BFRT, it is the responsibility of the practitioner to be familiar with the physiological mechanisms, proper application, pathoanatomic precautions, and pathoanatomic contraindications of the modality.[17,31,32] The author recommends that those looking to use BFRT in practice seek additional training beyond their traditional schooling to better provide the intervention safely and effectively.

Contraindications for the use of BFRT are centered on cardiovascular issues and include but are not limited to a history of or potential for a deep vein thrombosis/embolism, history of rhabdomyolysis, poor circulation, varicose veins, history of endothelial dysfunction, peripheral vascular disease, diabetes, easy bruising, active infection, cancer, lymphedema, renal compromise, pregnancy, use of medications that increase the risk of clotting, open wounds, presence of a tumor, sickle cell anemia, acidosis, the presence of a dialysis port, open fracture, increased intracranial pressure vascular grafts, lymphadenectomy, and intolerance to the intervention.[17,20,24,26,33] It is interesting to note that previous studies have examined the incidence of deep vein thrombosis while utilizing BFRT and found it to be <0.06%; likewise, the incidence of pulmonary embolism was found to be <0.01% and the reported instances of rhabdomyolysis after BFRT 0.008%.[34,35]

The previous list of contraindications should not be viewed as absolute or comprehensive. All individuals should be appropriately screened before any implementation of BFRT. Those at the greatest risk of an adverse reaction from BFRT are those with a poor circulatory system, obesity, sickle cell trait, severe hypertension, renal compromise, diabetes, or arterial calcification.[33] Potential adverse side effects to BFRT include but are not limited to pain or discomfort, delayed-onset muscle soreness, cardiac stress, numbness or nerve injury, bruising or ischemic injury, dizziness, fainting, muscle damage, thrombus formation, and rhabdomyolysis.[17,20,35,36] Clinical prediction rules, such as the Wells criteria, can be used to help practitioners assess the probability of venous thromboembolism in at-risk individuals.[20,37, 38, 39] Nascimento et al.[31] created a comprehensive screening tool that provides practitioners with a risk stratification specific to the use of BFRT. Practitioners should use their clinical judgment and knowledge of risk factors before implementing any BFRT intervention, and additional BFRT-specific training is recommended to ensure the safe and effective use of the intervention.

Application

BFRT is classically completed with low-load resistance training at 20% to 40% of estimated 1RM with and without neuromuscular electrical stimulation.[21,23,40] It can also be used with traditional high-load resistance training (>60% of estimated 1RM), in aerobic exercise (AE) at <45% of estimated maximal oxygen consumption (VO_2 max), and in passive cell-swelling protocols.[21,23,40] The commonality between each mode of BFRT is as a method to mitigate atrophy and serve as a means of additional training volume at a decreased intensity or an additional stimulus for hypertrophy in load-compromised individuals.

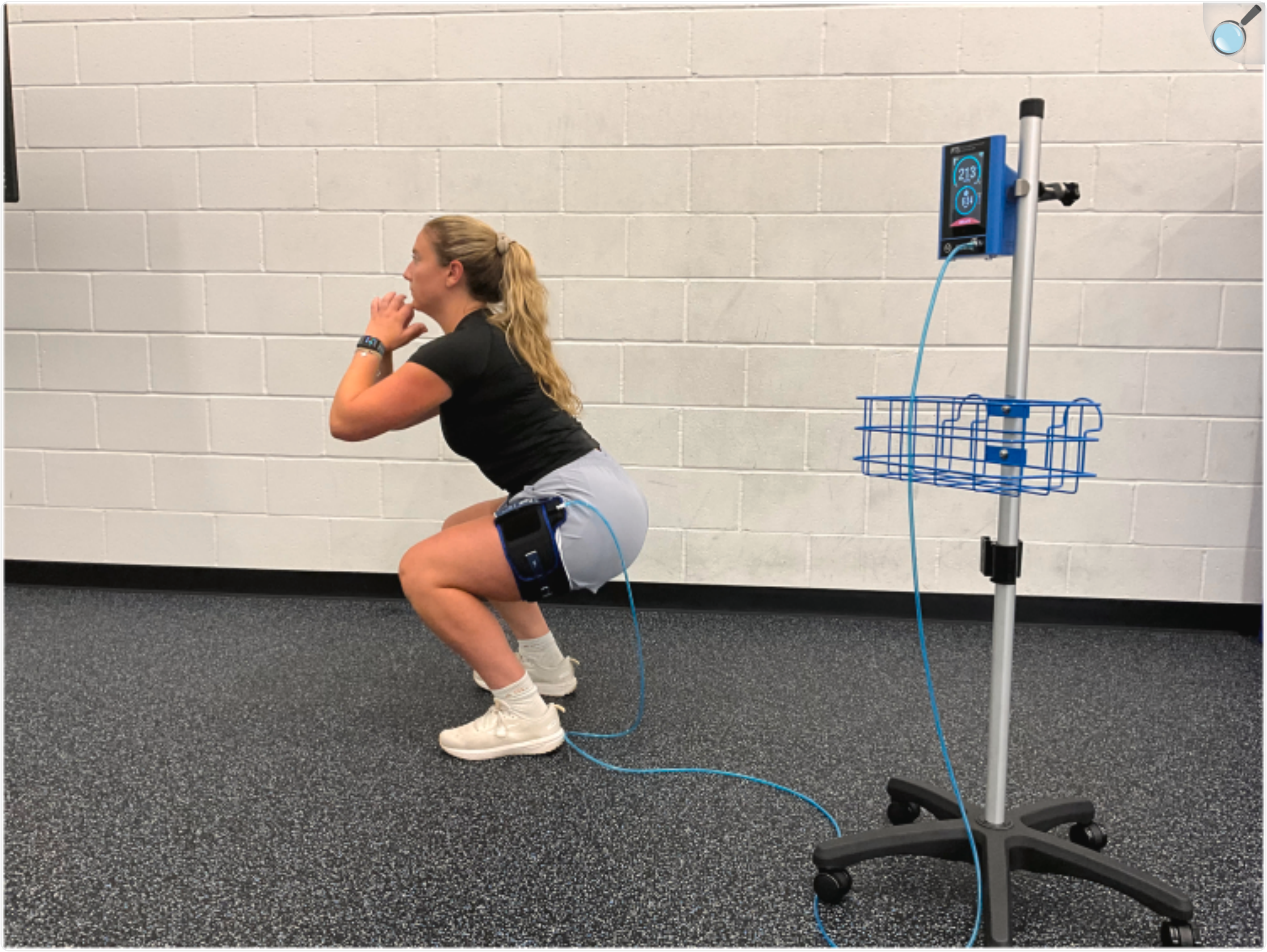
Regardless of the mode of intervention, a pneumatic tourniquet system or tourniquet cuff is placed proximally on the working limb(s) to allow occlusion to occur in the associated musculature.[17,20,35] The placement of the cuff should be as proximal on the working limb as possible to target the whole muscle group, allow for a full range of motion during exercise, and mitigate any risk of superficial nerve compression.[17,34,41] The use of a barrier between the skin and the cuff has also been recommended to mitigate any risk of superficial skin breakdown secondary to friction.[36] Before beginning BFRT, it is imperative to standardize limb occlusion pressure (LOP) specific to both the individual using the device and the position in which they will be exercising. Factors influencing LOP are cuff width, cuff material, cuff shape, limb circumference, limb characteristics, resting blood pressure, limb temperature, and position of the individual.[17,19,23,41] Use of a wider BFRT cuff has been shown to require lower pressure required to occlude the limb and produce fewer subjective reports of local discomfort.[24,41]

When selecting LOP, a recommendation of 40% to 80% of arterial occlusion pressure is suggested in the lower extremities (LEs) while up to 60% is advised the upper extremities (UEs).[20,21,24] The pressure utilized during BFRT should be low enough to preserve arterial inflow but high enough to occlude venous return in the working muscles.[41,42] Distal pulses must always be palpated when identifying LOP regardless of the type of equipment being used.[17] In any training intervention, reproducibility and safety are of the utmost importance, and BFRT is no exception. The gold standard is the use of a personalized tourniquet system with dynamic capabilities that can maintain and regulate a specified LOP pressure based on pressure fluctuations during movement. In the event this type of system is not available, LOP can also be determined using a manually inflated cuff and Doppler ultrasound.

BFRT in Rehabilitation, Recovery, and Performance

Traditionally, the use of low-load (LL) BFRT has been popular with load-compromised individuals. Acute program variables for LL BFRT include an overall frequency of 2 to 3 times a week, performed at 20% to 40% of estimated 1RM, for 5 to 10 minutes per exercise with reperfusion in between exercises.[17,20,21] In this structure, there are 2 to 4 sets, with a 30- to 60-second rest period between sets, using a repetition scheme totaling 75 repetitions divided into the 4 sets in a 30-15-15-15 fashion or to volitional fatigue (Fig 1).[17,20,21]

Fig 1.



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Athlete is performing a body weight exercise paired with blood flow restriction training to elicit improvements in skeletal hypertrophy and mitigate disuse atrophy despite being in a load-compromised state.

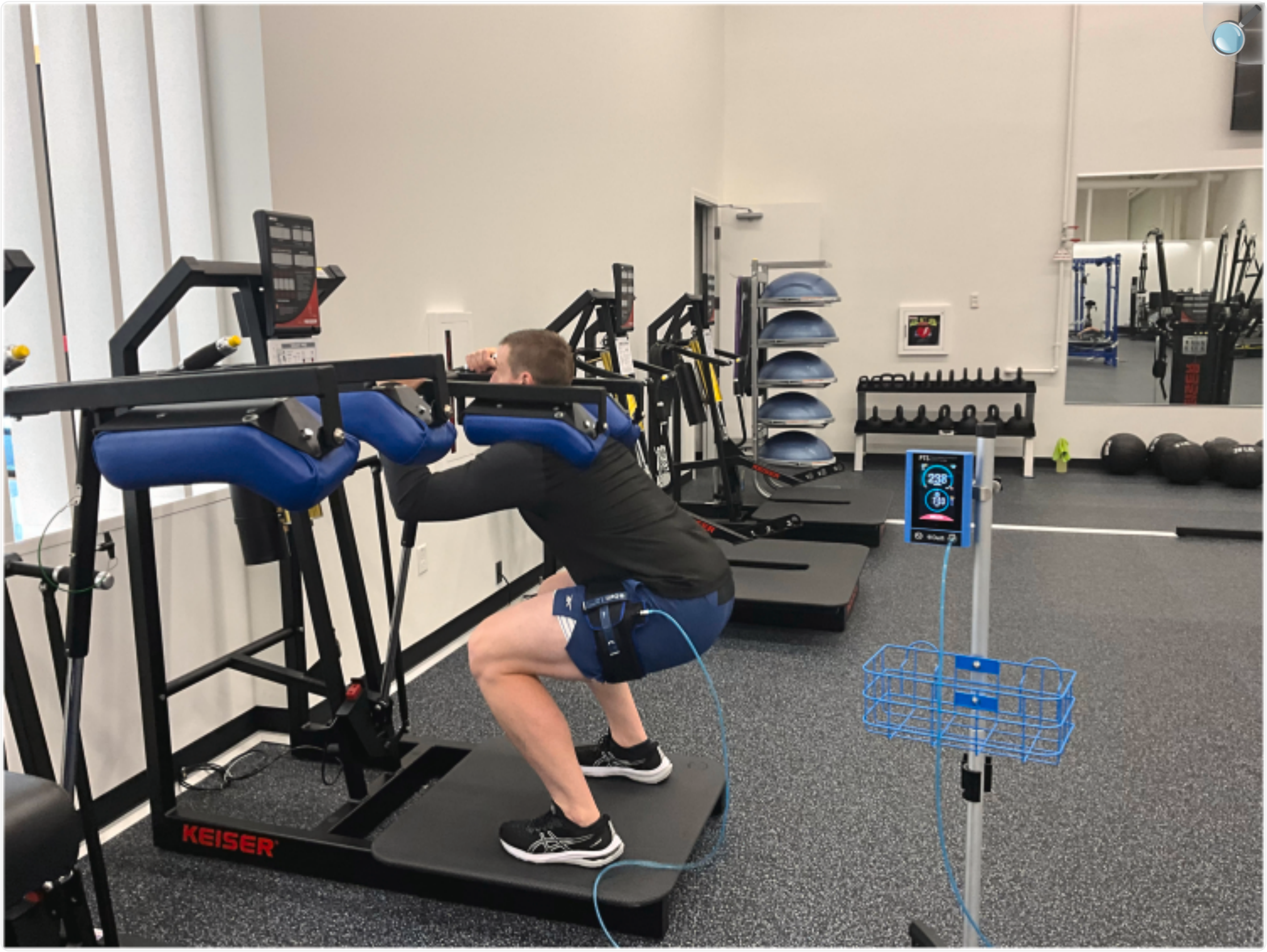
LL BFRT has been shown to be an effective modality in postoperative anterior cruciate ligament, Achilles tendon, total knee arthroplasty, knee arthroscopy, and quadriceps tendon rehabilitation as an early muscular training tool, improving strength, preserving LE bone mass, and mitigating atrophy.[33,43, 44, 45, 46] Additional studies have compared the effectiveness of traditional heavy-load resistance training and LL BFRT in the postsurgical rehabilitation of anterior cruciate ligament reconstructions, finding that LL BFRT can improve skeletal muscle hypertrophy and LE strength at similar levels of traditional heavy-load resistance training, with less joint pain and effusion.[47, 48, 49]

LL BFRT has demonstrated utility in the rehabilitation and management of both operative and nonoperative UE injuries such as shoulder stabilization procedures, pectoralis major tendon repairs, lateral elbow tendinopathy, rotator cuff injuries, distal radius fractures, and shoulder instability.[50, 51, 52, 53, 54, 55, 56, 57] LL BFRT has been shown to elicit changes in strength and hypertrophy both proximal and distal to the cuff in the UE.[25,50,51] Changes in strength and hypertrophy proximal to the cuff are thought to occur due to training to volitional fatigue, bringing about synergistic involvement of the proximal muscle groups.[51,54,58] LL BFRT in the UE appears to provide a greater increase in muscle strength and size than low-load resistance training alone.[54] Utilizing LL BFRT in individuals with a load-compromised UE appears to be an appropriate training stimulus to improve strength and hypertrophy. Further research in the area of BFRT and its effects on the UE can be of benefit as there is variance in the literature, particularly in regard to protocol standardization.[51] Additionally, it is worth noting that there is a scarcity of studies on the use of BFRT in healthy tendons and in the management of tendon pathology for both the UE and LE. Integrating LL BFRT may have utility as an adjunctive loading scheme in the acute phases of tendinopathy management when traditional heavy loads may not be tolerable.[59]

There is consistent evidence in the literature that LL BFRT produces more significant improvements in muscle strength and hypertrophy in the UE and LE when compared to traditional low-load resistance training in healthy individuals.[54,60] LL BFRT has been shown to be as effective at improving strength and hypertrophy in healthy individuals when compared to heavy-load strength training.[61, 62, 63] This demonstrates that LL BFRT is indeed a valuable tool when seeking a progressive training stimulus in load-compromised individuals or in otherwise healthy well-trained athletes requiring supplemental hypertrophy in targeted muscle groups who would not normally benefit from using low loads alone.[19,64,65]

Since PCSA of a muscle is a foundational performance factor for the expression of strength and power, it is interesting to note that a number of key sports performance indicators have been shown to improve through the addition of BFRT in healthy trained athletes, including 10-m, 30-m, and 40-m sprint times; counter-movement jump power; muscular endurance; 5-0-5 agility test; 20-m shuttle run test; 1 RM bench press; 1 RM squat; isokinetic strength of the knee flexors/extensors; cross-sectional area of the quadriceps muscle; and expression of isometric strength.[19,63,66, 67, 68, 69, 70, 71, 72, 73, 74, 75, 76] It is important to note there is variance in these studies in terms of effect size, exercise protocol, duration of training regime, intensity of loading, and LOP utilized. The implementation of BFRT alongside a traditional heavy resistance training program can be used as a progressive stimulus in either chronically or acutely load-compromised individuals and otherwise healthy athletes to continue to drive muscular hypertrophy and elicit improvements in conventional sport performance tests (Fig 2, Video 1).[19,54,60, 61, 62, 63,77,78]

Fig 2.



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Athlete is performing an axial loaded squat with blood flow restriction training as a driver for supplemental hypertrophy targeting the quadriceps under pneumatic resistance with a range-of-motion stop set by the clinician on the machine.

Aerobic fitness is a foundational performance factor to the repeated expression of strength and power and a marker of general health. A model of exercise prescription for BFRT with AE is utilization 2 to 3 times a week at an intensity of <50% of VO_2 max or heart rate reserves, an occlusion time of 5 to 10 minutes, and a mode of exercise of either cycling or walking.[17,20,78] Blood flow restriction (BFR) with AE has demonstrated significant improvements in aerobic capacity (AC) when compared to low- to moderate-intensity aerobic exercise without BFR.[75,78] When comparing high-intensity

(>90% of VO_2 max) AE with and without BFRT, there is minimal difference in improvement in AC.[78,79] However, there is significant improvement in anaerobic capacity and power without compromising maximal AC, suggesting the improvements in BFRT training with high-intensity AE are muscular rather than cardiovascular in nature.[79,80] This suggests that BFRT affords a more efficient and alternative avenue to improve AC at lower intensities utilizing novel training stimuli in the pursuit of improvements in anaerobic outputs at higher intensities.[81]

BFRT without additional exercise or passive BFRT is another mode of BFRT used in individuals who are encountering prolonged periods of immobilization, leading to large deficits in functional mobility and atrophy.[21,77] The induced cell-swelling in passive BFRT has been shown to facilitate the accumulation of metabolites and anabolic signaling.[77,82] Suggested parameters for passive BFR or cell-swelling protocol utilize a LOP of 70% to 100% for 5 minutes and then 3 minutes of reperfusion with a frequency of 3 to 4 sets per session with a maximum occlusion time of 20 minutes, once to twice a day.[20,40,83]

Another application of passive BFRT is ischemic preconditioning (IPC). This is a tool to enhance the recovery process, which has been shown to attenuate the markers of exercise-induced muscle damage.[84] IPC has potential usages in application before and/or after strenuous exercise to help expedite recovery and restore contractile properties of the tissues after activity or prime the tissues before engaging in the task.[84, 85, 86] IPC after eccentric exercise has been shown to decrease markers of exercise-induced muscle damage, reduce overall soreness, and enhance postexercise muscle performance.[87,88] IPC could serve as a tool to optimize athlete readiness and availability as a priming tool before participation in sport or training and/or as a recovery method after an exposure to sport/training.

Conclusions

BFRT has applications across the continuum of human performance, from immobilization, early rehabilitation with low loads, low-intensity aerobic exercises, as part of a comprehensive strength and conditioning plan, and in recovery. The use of conventional strength training is strongly supported along with the inclusion of BFRT as an adjunct in the otherwise healthy population to optimize mechanical tension, muscle damage, and metabolic stress to drive muscle growth. It is our role as performance coaches and rehabilitation providers to restore, refine, and prepare the relevant structural and functional qualities of the individual for the task in which they will be participating. Muscular hypertrophy is a foundational performance precursor to be able to express and withstand the biomotor, sensorimotor, and bioenergetic demands of sport. BFRT is a progressive training stimulus that can be incorporated across a variety of populations, in number of applications, to produce a more resilient individual.

Disclosures

The author (M.M.) declares that they have no known competing financial interests or personal relationships that could

have appeared to influence the work reported in this paper.

Supplementary Data

Video 1

Athlete is performing an axial loaded squat with blood flow restriction training as a driver for supplemental hypertrophy targeting the quadriceps under pneumatic resistance with a range-of-motion stop set by the clinician on the machine.

Download video file (4MB, mp4)

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Associated Data

This section collects any data citations, data availability statements, or supplementary materials included in this article.

Supplementary Materials

Video 1

Athlete is performing an axial loaded squat with blood flow restriction training as a driver for supplemental hypertrophy targeting the quadriceps under pneumatic resistance with a range-of-motion stop set by the clinician on the machine.

Download video file (4MB, mp4)